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Evaluation of Single Common Powertrain Lubricant (SCPL) Candidates for Fuel Consumption Benefits in Military Equipment

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ABSTRACT

The Single Common Powertrain Lubricant (SCPL) program is seeking to develop an all-season (arctic to desert), fuel-efficient, multi-functional powertrain fluid with extended drain capabilities. To evaluate candidate lubricants for the purpose of fuel consumption effects, a test cycle was developed using the GEP 6.5L(T) engine found in the HMMWV. Field data collected at Ft. Hood, TX was used to determine a set of speed, load and temperature points which could be reproduced consistently in test-cell operation. These points were condensed into a 14-mode cycle for use within the SCPL program. In addition to fresh condition oil, some lubricants were evaluated at end-of-life drain conditions to determine consumption effects over time. Results from the program indicated a significant fuel consumption benefit with lower viscosity lubricants when compared to current in-use military engine oils.

INTRODUCTION

The Single Common Powertrain Lubricant (SCPL) program goal is to develop an all-season (arctic to desert), fuel-efficient, multi-functional powertrain fluid with extended drain capabilities. This program utilizes state-of-the-art base oil and additive technologies to significantly improve upon current military engine and transmission lubricants and enable future powertrain technologies. Previous phases of the program demonstrated the technical and economic feasibility of the low viscosity SCPL concept [1]. In the current phase, lessons learned from the technical feasibility study are being used to guide the development of candidate SCPLs. This paper outlines the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) development of a method to discriminate SCPL candidate lubricants on the basis of fuel consumption. Two distinct groups exist in dynamometer engine fuel consumption test procedures: standardized test procedures, and industry-accepted or developmental test procedures. Many of the available test procedures are more applicable to light-duty diesel applications than heavy duty diesel applications, and specific fuel consumption engine dynamometer standardized test procedures for heavy-duty diesel engines are thus far non-existent. This is likely due to the focus on extended engine durability, emphasis of emissions reductions, and exhaust aftertreatment development that is currently driving

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research within the heavy-duty diesel industry. Another option for heavy-duty diesel fuel consumption testing is an in-vehicle method such as the SAE J1321 test; however, this is a very cost- and labor-intensive choice [2].

APPROACH

Current technology for evaluation of engine oil fuel efficiency is represented by standardized laboratory test procedures, including CEC L-54-T-96 M111, ASTM D6873 Sequence VIB, and Sequence VID. None of these tests, however, provide a proper representation for military vehicle applications. To create a test representative of actual vehicle use, a High Mobility Multipurpose Wheeled Vehicle (HMMWV) at Ft. Hood, TX was instrumented through two multi-week training missions [3]. Oil temperature, engine speed, vehicle speed, and throttle position were recorded. This collected data set was used to define 26 distinct load, speed, and temperature points. These points were then replicated on a dynamometer test stand. An image of the stand is shown in Figure 1.

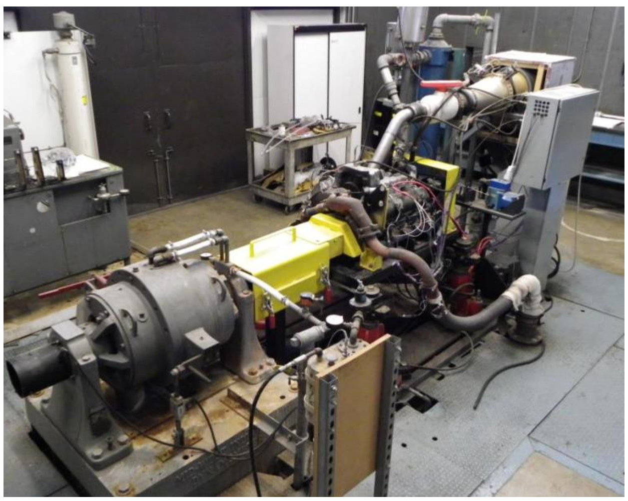

Figure 1: 6.5L(T) Dynamometer Test Stand

Fuel inlet temperature and inlet air temperature were maintained at a constant 95°F and 75°F respectively. JP8 was used as the test fuel throughout the entire project. Coolant and oil temperatures were controlled at increasing values from step to step. An SAE 40 weight oil was used as the baseline lubricant for test development. Each point was operated for 15 minutes to ensure stabilization prior to data collection. Figure 2 shows the test points in relation to a wide-open throttle torque curve. While only 21 load-speed points appear in the figure, some are repeated at multiple engine oil temperatures.

After multiple repetitions of the cycle, it was determined that a simplified cycle would increase the rate at which oils could be evaluated and improve the repeatability of the test in TFLRF facilities. From the 26 points, duplicate speed and load points were eliminated and steps were ordered for increasing oil temperature during the test. Two steps were added for high-speed, high-load conditions at the elevated oil temperature. A summary of the revised test cycle is shown in Table 1 with graphical representation in Figure 3, which compares the fuel consumption cycle to a wide-open throttle torque curve. The line connecting the points indicates the order in which they were run, starting with 1100 RPM and 59.7 ft-lbs of torque.

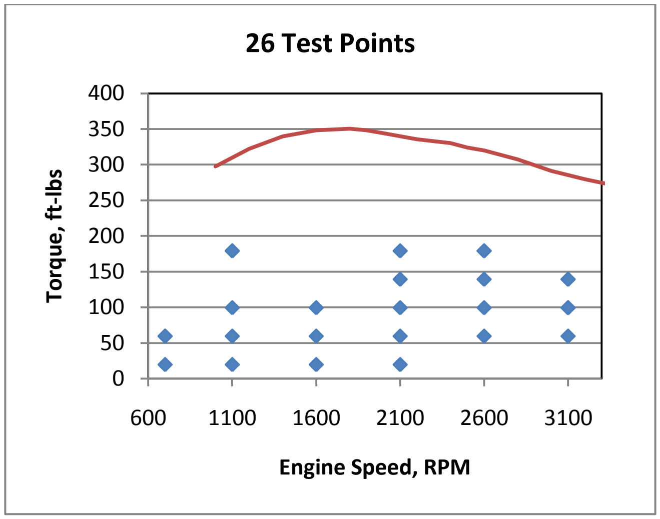

Figure 2: Original Test Points

Table 1: 14 Point Test Cycle

Point	RPM	Torque, ft-lbs	Power, hp	Oil Sump, ˚F
1	1100	59.7	12.5	165
2	2100	59.7	23.9	180
3	1100	99.6	20.9	
4	1100	179.2	37.5	
5	1600	99.6	30.3	195
6	2100	139.4	55.7	
7	2600	99.6	49.3	215
8	2100	179.2	71.7	
9	3100	99.6	58.8	
10	2600	139.4	69.0	
11	3100	139.4	82.3	245
12	2600	179.2	88.7	
13	2400	302.4	138.2	
14	2800	250.8	133.7	

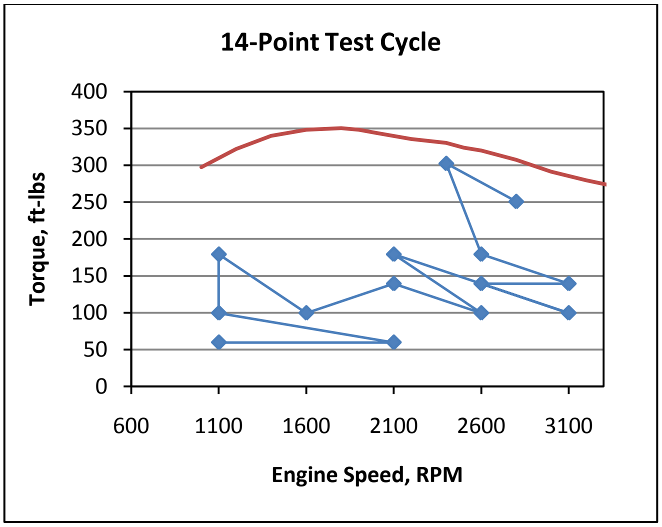

Figure 3: 14-Point Test Cycle

Out of the 15 minute run time for each step, data from the last five minutes was used to determine a step Brake Specific Fuel Consumption (BSFC) value. The BSFC value was then weighted based on the fuel flow rate at each step, with high flow rates receiving a higher weighting factor. The weighting factor for each step is shown in Table 2. The weighting factors were developed through the SAE 40 oil testing, but remained unchanged for other lubricants.

Table 2: BSFC Weighting Factors

Step	Weighting Factor
1	0.02
2	0.04
3	0.03
4	0.04
5	0.04
6	0.06
7	0.07
8	0.07
9	0.09
10	0.09
11	0.11
12	0.1
13	0.13
14	0.14

The weighted values were summed to produce a cycle BSFC value. Each oil was run seven times to obtain results for statistical analysis. Results from a complete SAE 40 oil test are shown in Table 3.

Table 3: SAE 40 BSFC Results

SAE 40		
	Fuel Used, gal	BSFC, lb/hp-hr
Run 1	15.7	0.4960
Run 2	15.75	0.4972
Run 3	15.77	0.4970
Run 4	15.68	0.4945
Run 5	15.62	0.4921
Run 6	15.65	0.4934
Run 7	15.7	0.4949
Average	15.70	0.4950
Std. Dev.	0.05	0.0019
COV	0.33%	0.38%

A MIL-PRF-21260 SAE 10W oil was used to evaluate the procedure's ability to discriminate between fluids. The fluids showed a significant difference (3.08%) in BSFC, as shown in Table 4.

Table 4: Fuel Consumption Changes: SAE 40 to SAE 10W

	Run	Cycle BSFC
SAE 40	1	0.4960
	2	0.4972
	3	0.4970
	4	0.4945
	5	0.4921
	6	0.4934
	7	0.4949
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
MIL-PRF-21260 SAE 10W	1	0.4810
	2	0.4804
	3	0.4802
	4	0.4799
	5	0.4809
	6	0.4793
	7	0.4775
	Average	0.4798
	Standard Deviation	0.0012
	COV	0.25%
Percent Change: SAE 40 to SAE 10W		3.06%

To evaluate long-term repeatability, the SAE 40 oil used in development of the test was run multiple times. Over a six-month period the engine showed an engine drift in the average BSFC of 0.24% using the same batch of SAE 40 oil. This change was not statistically significant at a 95%

confidence interval and indicated the engine to be an effective method for testing fuel consumption changes from SCPL candidates and other lubricating oils. The comparative results from the two tests are shown in Table 5.

Table 5: Fuel Consumption Changes: Test Stability

	Run	Cycle BSFC
SAE 40 Run 1	1	0.4960
	2	0.4972
	3	0.4970
	4	0.4945
	5	0.4921
	6	0.4934
	7	0.4949
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
SAE 40 Run 2	1	0.4980
	2	0.4946
	3	0.4925
	4	0.4935
	5	0.4960
	6	0.4912
	7	0.4909
	Average	0.4938
	Standard Deviation	0.025
	COV	0.52%
	Percent Shift Over Six-Month Period	0.24%

SCPL CANDIDATE TESTING

For the purpose of testing SCPL candidates, a new engine was built and installed in the test cell. A run-in process of 100 hours was conducted on the engine followed by back-to-back fuel consumption tests to indicate if stability had been reached. Results from this test are shown in Table 6. The shift in Cycle BSFC value was not statistically significant.

Table 6: Fuel Consumption changes: Engine Break-In

	Run	Cycle BSFC
New Engine SAE 40 Run 1	1	0.5131
	2	0.5147
	3	N/A
	4	0.5108
	5	0.5150
	6	0.5108
	7	0.5111
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
New Engine SAE 40 Run 2	1	0.5152
	2	0.5130
	3	0.5142
	4	0.5148
	5	0.5140
	6	0.5145
	7	0.5139
	Average	0.5142
	Standard Deviation	0.0007
	COV	0.14%
	Percent Shift After Break-In	-0.32%

Throughout the project, the baseline oil was run prior to each candidate lubricant to account for shifts in engine performance. In addition to the fuel consumption benefit from fresh oil, selected lubricants were tested at the end of useful life to determine the indicated fuel consumption benefit at the time of drain. Following the evaluation of fresh oil, the end-of-test (EOT) drain from SCPL endurance tests was placed in the engine and an additional seven-cycle test was conducted. These EOT oils ran from between 140 and 168 hours of the Tactical Wheeled Vehicle Cycle to break the oil. Testing was performed based on the condition of the EOT oil and deemed unsuitable for some candidate lubricants. Table 7 shows the change in fuel consumption between each candidate lubricant and the baseline SAE 40 oil. All results shown were statistically significant shifts. In addition to experimental lubricants, two commercially available products were evaluated for comparison.

Table 7: Candidate Lubricant Test Results

Lubricating Oil	% Improvement Fresh	% Improvement EOT
MIL-PRF-2104G SAE 15W-40	0.83	N/A
MIL-PRF-2104H SAE 15W-40	0.86	N/A
MIL-PRF-46167 OEA-30 (Batch 1)	2.27	1.26
MIL-PRF-46167 OEA-30 (Batch 2)	2.38	N/A
Experimental Arctic Oil 1	2.51	2.01
Experimental Arctic Oil 2	2.51	N/A
Experimental SAE 0W-20	2.41	1.83
Experimental SAE 0W-30	2.00	0.37
Commercial SAE 15W-40	0.27	-2.14
Commercial SAE 5W-40	0.36	N/A
Experimental Tractor Oil	1.54	N/A

CONCLUSIONS

The use of low viscosity engine oil was shown to have a significant impact on fuel consumption. Additionally, the difference between the current MIL-PRF-2104H SAE 15W-40 grade and the best experimental fluid had an improvement of 1.66% over the test cycle. This value is not far from a 1.5% improvement previously seen in SAE J1321 testing with MIL-PRF-2104G SAE 15W-40 grade and an early candidate oil [4]. Although the J1321 testing was conducted in vehicles, on a different drive cycle, with a different engine and uncontrolled temperatures, the similarity in results is encouraging. Even at end-of-life conditions, three of the four low viscosity oils available showed an improvement over the currently used product. While improvements of this magnitude may not be noticeable with a single vehicle, the potential exists for substantial fuel savings when applied over the entire ground vehicle fleet.

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